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(Original article)

Development of a dental implant movement checker

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Summary

Evaluation of dental implantation is very important because it gives useful information for both planning the dental treatment and evaluating of prognosis. This study aimed at improving our previously developed Tooth Mobility (TM) tester and developing a dental implant movement (IM) checker. The measuring probe included a bimorph transducer of two piezoelectric elements. It was actuated by single frequency and detected tooth acceleration. The acceleration signal was processed and the IM score was calculated in PC. Two artificial implant models in which IMZ implant was buried with different elasticity of surrounding (molteno®) were used to examine the performance of the IM checker. The IM scores obtained in the models were 29 and 58. The measurement time was below 15 seconds. The average of measurement variation of one operator was below 6 % and the average variation among five operators was below also 6 %. The IM checker reduced a measurement variation by 51 % and a measuring time by 61 % compared with those of the TM tester in natural teeth. The newly developed IM checker had sufficient measuring reliability and we could objectively estimate the implant movement in dental clinics.

Key words: tooth mobility, mechanical mobility, dental implant, manual examination

Introduction

Dental implantation is necessary for replacing one or more missing teeth and it will enhance the quality of life of the aged. An evaluation of dental implantation, however, is not established in clinic. Until now, the quality of dental implant has been estimated by radiographic findings and qualitative appearance (occlusion, gingival inflammation, exudates, *etc.*) after dental implant treatment[1)]. However, they do not provide sufficient information.

An examination of implant movement is important for estimating a success or fitness of implantation. Generally, manual examination is performed for evaluating tooth mobility, but it cannot be applied to dental implant examination. There are several studies, in which the tooth mobility and implant stability were assessed objectively or non-invasively in clinical diagnostic methods[2-9)]. Kaneko *et al.* utilized high frequency pulse signals to assess mechanical state of an implant[3, 4)]. This technique has been applied in clinical diagnosis but it was relatively difficult to measure in the mouth, because they used two pins - one acted as an actuator and the other acted as a sensor. The result depended on touching force, which was quite difficult to control. The other technique is PERIOTEST®, which has been designed to measure natural tooth mobility objectively[2)]. Many dentists have applied it as a diagnostic tool for dental implants. Periotest reading has wide range scale for healthy and pathological teeth. Since dental

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implants hardly move, it is difficult to assess the implant movement with Periotest accurately. Moreover, it may damage a dental prosthesis, may cause pain to a patient, and may damage an implant cylinder during an early stage of implant treatment, since the Periotest gives relatively strong impact force to them.

We had already developed a Tooth Mobility (TM) tester for estimating natural tooth mobility quantitatively[8]. In this tester, we applied a single sine vibration on a natural tooth and detected an acceleration response using a measuring probe, which consisted of a set of bimorph piezoelectric transducer. We applied the same principle of TM tester and developed an Implant Movement (IM) checker. In this study, we focused on designing of IM checker, a measuring probe, and a data acquisition program. In order to obtain the appropriate measuring conditions, we examined the IM checker on natural teeth. Moreover, we verified its performance by using artificial tooth models and implant models.

Methods

The implant movement was estimated by investigating mechanical mobility, $\lambda(f)$[10] of a dental implant buried in the alveolar bone. The mechanical mobility is a reciprocal to the mechanical impedance and expressed as:

$$\lambda(f)=\frac{V(f)}{F(f)}=\frac{1}{j\omega}\frac{A(f)}{F(f)} \qquad (1)$$

where $F(f)$, $V(f)$ and $A(f)$ shown in Fig. 1 are Fourier transforms of the applied force to the mechanical system, $f(t)$, the velocity, $v(t)$, the acceleration, $a(t)$ at driving point, f is a measuring frequency and $\omega=2\pi f$. The applied force, $F(f)$ and the acceleration, $A(f)$ at driving point are shown in Fig. 1.

In case for constant measuring frequency and constant applied force, the eqn.(1) becomes:

$$A=k\lambda \qquad (2)$$

where $k=2\pi fF$. The index of implant movement, IM score, is defined proportional to the acceleration at the driving point according to the following equation as:

$$IM=k'A=k'k\lambda \qquad (3)$$

where k' is proportionality constant between the IM score and the acceleration. Fig. 2 shows a photograph of the developed IM checker with a measuring probe.

1. Design of IM Checker

The basic principle of the IM checker is the same as that of the TM tester[8]. The block diagram of the IM checker is shown in Fig. 3. It consists of a measuring probe, an amplifier unit and a note-type PC.

The sine vibration from an oscillator with constant amplitude was applied on the object through the

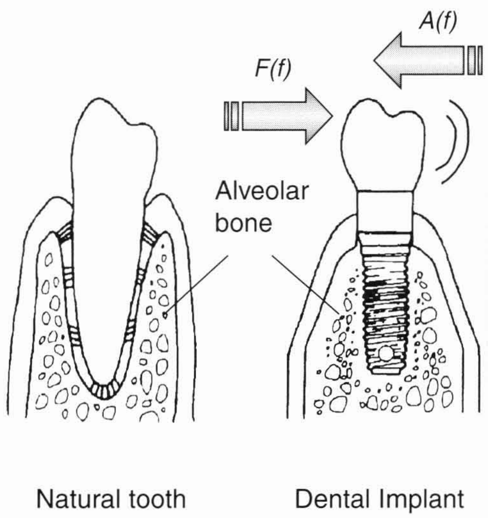

Fig.1 Applying force and acceleration at driving point of an implant.

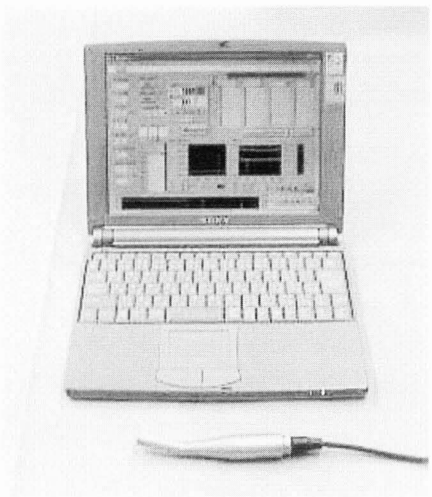

Fig.2 Photograph of the IM checker with a measuring probe.

actuator of measuring probe. The object such as tooth, tooth model or implant model, generated an acceleration response. This signal was so small that a charge amplifier was necessary to amplify the signals. At the same time, the contact pressure was detected and amplified by means of a strain amplifier.

The signal from the charge amplifier was fed into a band pass filter (BPF) with 415 Hz as its center frequency. The effective value of acceleration was obtained by a RMS/DC converter. This value and the output from the strain amplifier were fed into an ADC. The digital signals from the ADC were then processed in the note-type PC. The acceleration and contact pressure were displayed on the PC monitor in real time. After completing the acquisition procedure, the *IM* score was displayed on the PC monitor.

2. Measuring Probe

The design for measuring probe is very important because dental implants are often applied to premolar or molar regions in the mouth. We adopted the shape and size of a dental drill for the handle of measuring probe. The length of measuring probe was 38.5 mm and its diameter was 10 mm. The grip of the probe bent 15° to the top so as to handle in the mouth more easily. Fig. 4 shows a structure of the measuring probe. We used a set of two piezoelectric elements for the movement transducer of the probe. One was used as an actuator and the other as an acceleration detector. The size of transducer was 60 mm x 5 mm x 580 μm. The resonance

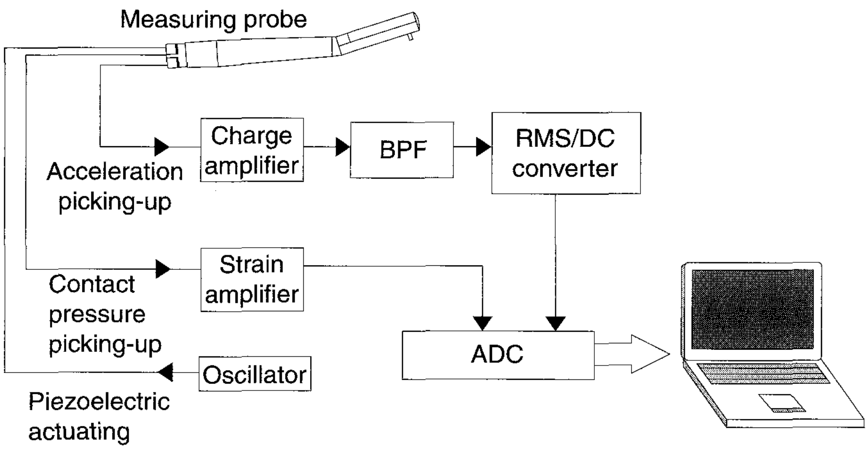

Fig.3 Block diagram of IM checker.

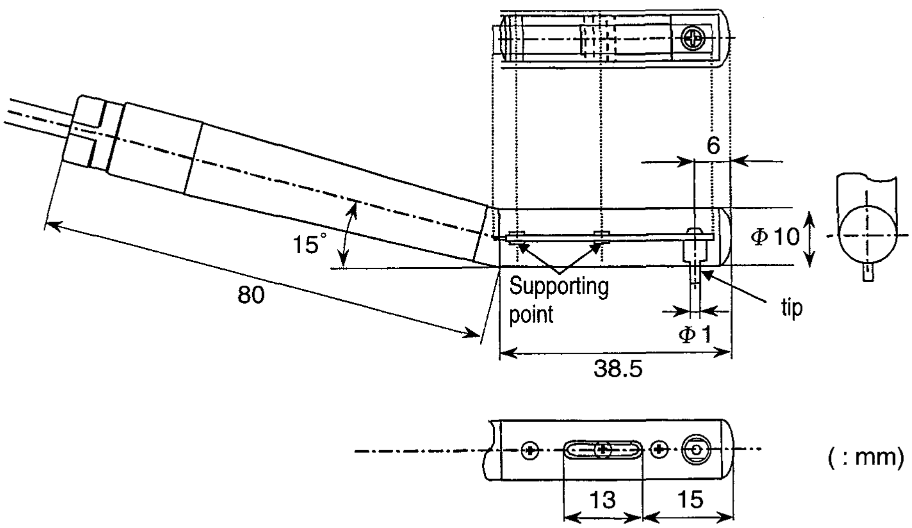

Fig.4 Structure of the measuring probe.

frequency of actuator was set at 415 Hz manually[8]. We used a strain gauge to measure a contact pressure. The strain gauge was attached to the ceramic surface of the transducer. As the implant movement depended on contact pressure, we should keep it at a constant pressure during the measurement.

3. Data Acquisition

Once the measuring probe touched to an object at a certain contact pressure, then it got an acceleration response of the object and its contact pressure. The signals were so small that they needed an amplifier unit and were processed by a data acquisition program. The small signals, however, still contained noises. The analog signal processing used in the TM tester was good for evaluating the natural tooth mobility. The implant movement, however, was smaller, that we adopted two different approaches of modifying the TM tester. First, we adopted a BPF with 415 Hz as its center frequency instead of HPF used in the TM tester. Secondly, we used Labview® system of digital signal processing for data acquisition. The flowchart of this processing is shown in Fig. 5.

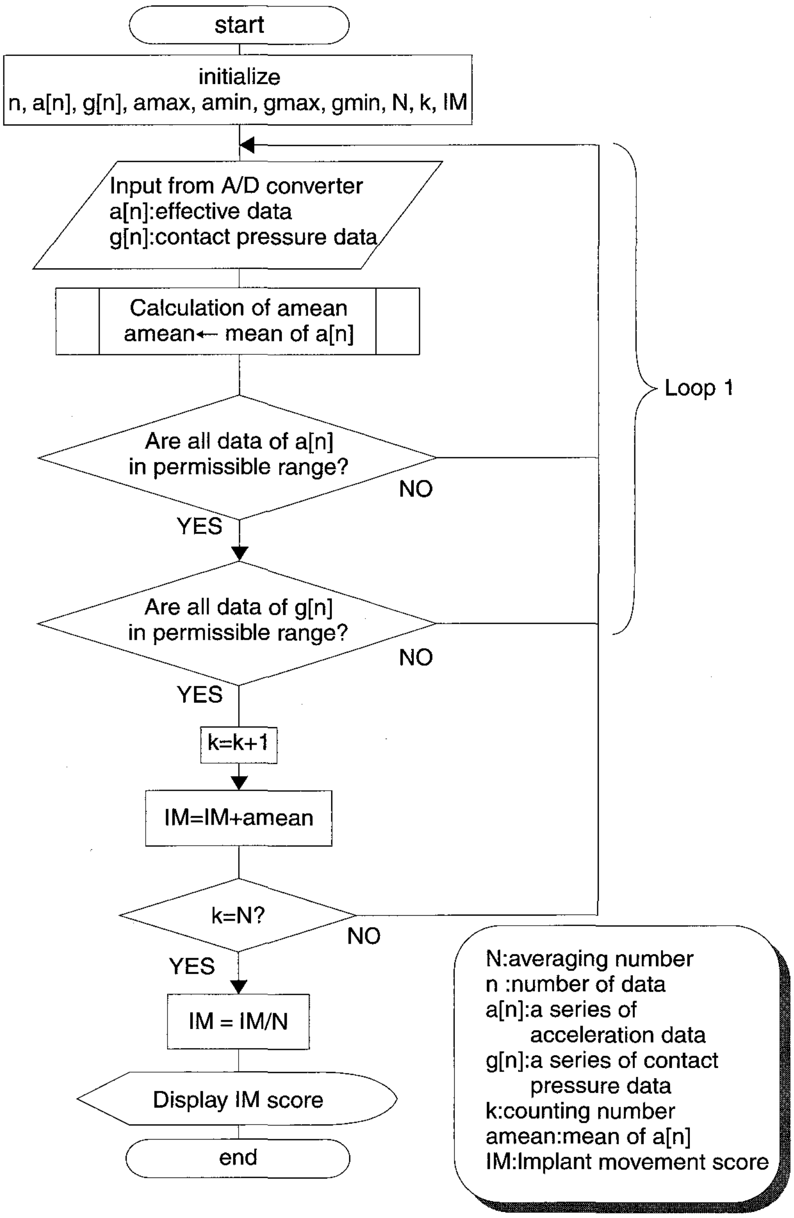

Fig.5 Flowchart of the measurement program.

There were several constants to be initialized in the data acquisition procedure, namely number of data in one sampling, n; averaging number, N; range of acceleration response, *amax* and *amin*; range of contact pressure, *gmax* and *gmin*. A series of data of acceleration and contact pressure were captured from the ADC and put into *a[n]* and *g[n]*. After capturing a series of data, the mean of acceleration was calculated and followed by checking procedure. The checking procedure for acceleration is shown in Fig. 6. The criteria for acceleration data are defined according to

$$A_c = amean \pm Ap \tag{4}$$

where *amean* is a mean of a series of acceleration in one data sampling, A_p is a permissible range of acceleration response and A_c is a boundary value of acceleration as defined in initializing procedure as *amin* and *amax*. If the acceleration data were out of this range, then they were considered to be noises and they were rejected. Only the acceleration data within the range were processed to the checking procedure of contact pressure. The range of contact pressure G_{pc} is presented below:

$$G_{pc} = \left(50 \pm 50 \times \frac{G_p[\%]}{100}\right) \text{[gf]} \tag{5}$$

where G_p is the ratio of permissible range of pressure and G_{pc} is the boundary value of pressure defined as *gmin* and *gmax* in initializing procedure.

If the data of contact pressure were within the range, the value of *IM* score was accumulated and the accumulation index, k was increased. If they were not in the range, then the program got another series of data and continued the checking procedures as described above. After N times of accumulation, the *IM* score was averaged and displayed on the PC monitor.

4. Artificial Tooth Model

A natural tooth moves within the range of the periodontal membrane in the alveolar bone[11]. The periodontal membrane of natural tooth is fibrous connective tissue and its major function is to support tooth in the alveolar bone.

We had made four artificial tooth models with four different thicknesses of artificial periodontal membrane. The cross section of this model is shown in Fig. 7. The artificial periodontal membrane was made of silicone impression material with thickness of 0, 0.28, 0.56, and 0.84 mm corresponding to M0, M1, M2 and M3 in clinical tooth mobility, respectively. The M0, M1, M2 and M3 scales represent clinically firm tooth mobility within normal range; palpable mobility, buccolingually; visible mobility, buccolingually but no mobility in a apical direction; and mobility in response to lip and tongue pressure, buccolingually in addition to mobility in an apical direction; respectively[12]. The periotest (PT) values of the four models were -1, 15, 24 and 37. In comparison with the clinical tooth mobility, the PT value can be broken down into the following ranges: M0 = -8 to +9, M1 = 10 to 19, M2 = 20 to 29 and M3 = 30 to 50[6].

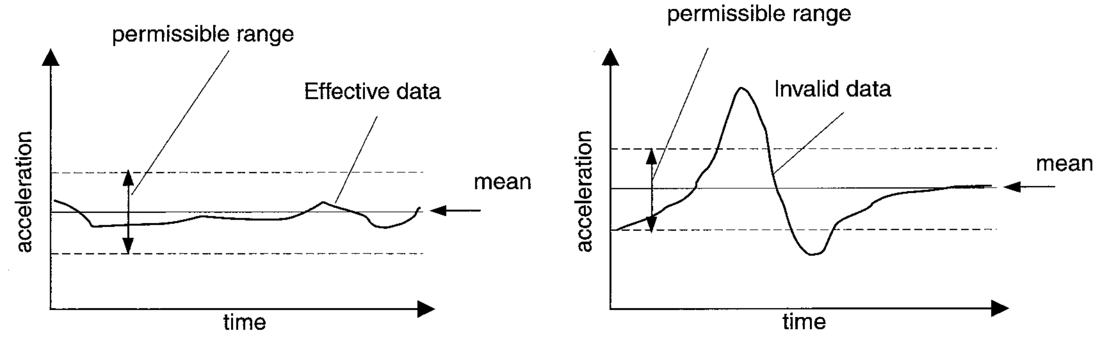

Fig.6 Noise reduction of acceleration.

5. Artificial Implant Model

As we could not find the most suitable model for dental implant movement available in this study, we made two artificial implant models as a standard of implant movement. The molteno® was adopted as surroundings of dental implant as shown in Fig. 8. The implant movement of artificial models could be adjusted by changing implant cylinder or implant's surroundings. We used regular-type and hard-type models depending on the hardness of molteno. Their Asker Hardness indexes were 82 and 89, respectively. Their clinical tooth mobilities were examined as M0 by two experienced dentists in clinic. The regular-type model was examined as being M0 but close to M1. The movement of dental implant is small and might be smaller than that of healthy teeth because it does not include a periodontal ligament[11]. Then it is significant to examine the implant movement within M0 range.

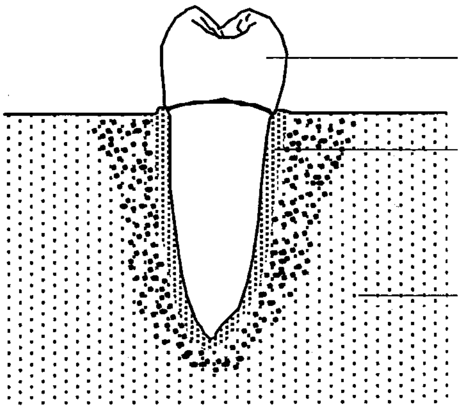

Fig.7 Artificial tooth model.

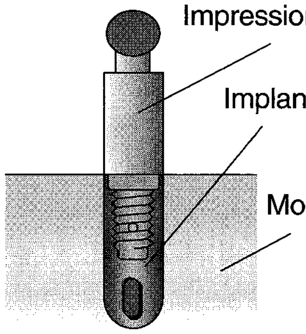

Fig.8 Artificial implant model.

Results and Discussions

In order to get the appropriate measuring condition, it was necessary to find suitable measurement constants. The four constants were the period to take a series of data from the ADC, T [s]; the ratio of permissible range of contact pressure, G_p [%]; the permissible range of acceleration, A_p [m/s^2]; and the number of data to be averaged, N. These parameters were obtained from measurements of natural teeth.

The results of various measurement conditions for maxillary teeth of first molar, second premolar, canine and central incisor are shown in Fig. 9. The variation was regarded as the measurement precision and expressed as:

$$variation = \frac{SD}{mean}\ [\%] \qquad (6)$$

where SD is standard deviation.

The variation became smaller as G_p became smaller, because G_p represented the tolerance of measurement. However, the measuring time became longer as G_p became smaller. In our constraint, the measuring time was less than 20 seconds. This was very useful especially for comfort of a patient. In this study we chose 5 % for G_p and other parameters were chosen as T = 0.1 s for 100 sampling data, A_p = 4.9 m/s^2, and N = 5. These parameters were set up in the computer program as initial constants.

We measured the tooth mobility of four artificial tooth models representing as M0, M1, M2 and M3 in clinical tooth mobility by the IM checker and the TM tester. The measurement results by IM checker and TM tester are shown in Fig. 10. Both the IM and MI scores (MI score is a Mobility Index obtained by the TM tester) increased corresponding to clinical tooth mobility. The SD of each measurement by the IM checker, however, was smaller than that by the TM tester. The IM scores for artificial tooth models were 5.3 ± 0.1, 6.9 ± 0.2, 11.6 ± 0.3, 28.2 ± 1.0 for M0, M1, M2 and M3, respectively. Their variations were very small, the maximum of variation was only 3.59 %, and then the repeatability of the IM checker was sufficient for evaluation of dental implantation.

We also compared the measurement time and variation between the IM checker and the TM tester.

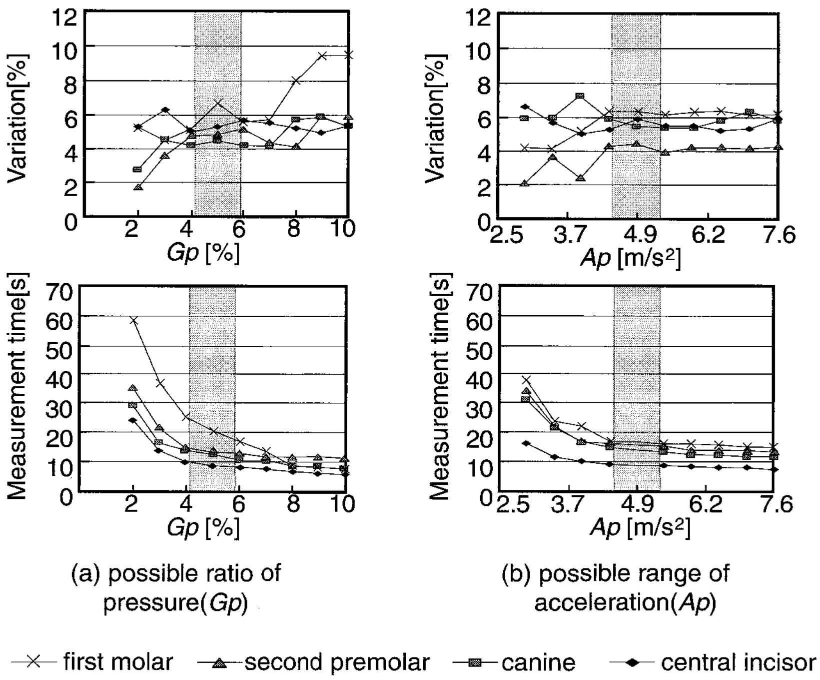

Fig.9 Variation and measurement time of maxillary teeth.

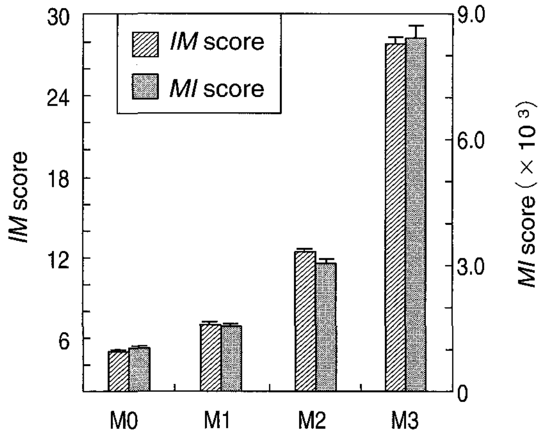

Fig.10 IM score compared to MI score.

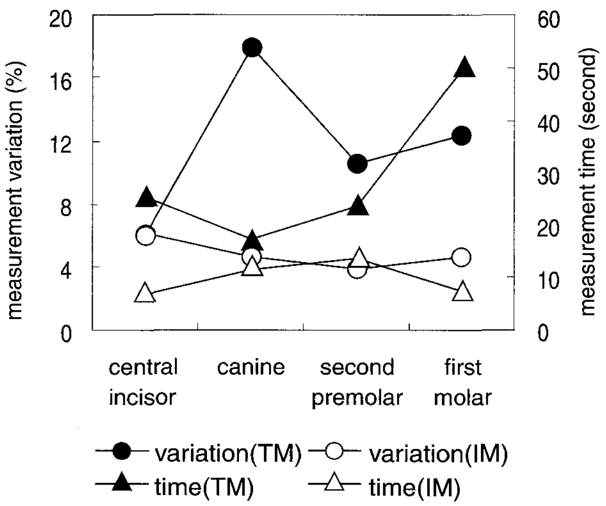

Fig.11 Measurement variation and time by using IM checker and TM tester.

The subject was a 22 year-old male. His periodontium was healthy. In the IM checker, we used 50 ± 1 gf as the contact pressure. It was assumed that this value was so small that a patient did not feel pain. Each tooth was measured 12 times. The results for four maxillary right teeth (central incisor, canine, second premolar and first molar) are shown in Fig. 11. The variation of the IM checker was much smaller than that of the analog TM tester for all teeth. The maximum measurement time by using the IM checker was below 15 seconds and the measurement variation was below 6 %. The variation of the IM checker was 51 % smaller than that of the TM tester and the measurement time of IM checker was reduced 61 % compared to that of the TM tester.

The mobility spectra of the two artificial implant models are shown in Fig. 12, which were obtained by using automatic diagnosis system[5]. As it is obvious from the figure, the mobility spectra of implant models at 415 Hz were quite distinct, we chose this frequency as a measuring frequency. The *IM* scores of two implant models are shown in Fig. 13. The

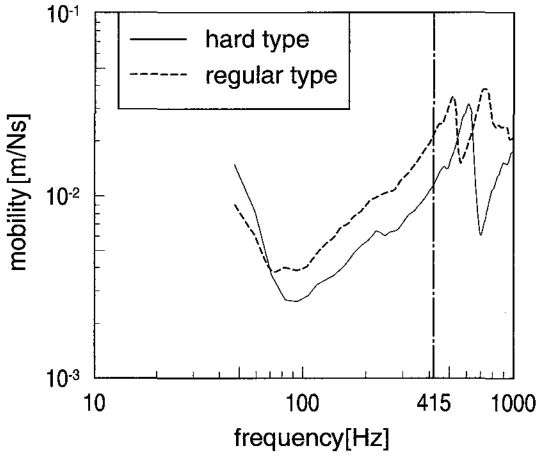

Fig.12 Mobility spectrum of artificial implant models.

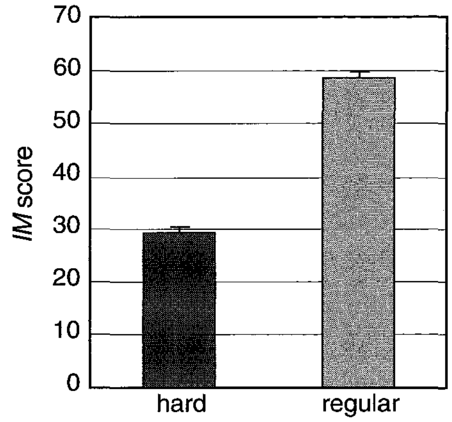

Fig.13 IM score of two different implant models.

results were consistent with eqn. (3) because the mechanical mobility of hard-type model was smaller than that of the regular-type model at 415 Hz as shown in Fig. 12.

The *IM* score, *SD* and the variation for the hard-type and regular-type models measured by five operators are shown in Table 1. Each operator measured the movement of each implant model 14 times. The average of repeatability for 14 measurements was 4.1 % for regular-type and 5.8 % for hard-type models. The average of *IM* score measured by five operators was 54.6 ± 2.2 for regular-type and 31.1 ± 1.8 for hard-type models. Thus, the measurement repeatability and the reliability among different operators were sufficient for clinical use.

Conclusions

The Implant Movement (IM) checker was made as the improved device of the Tooth Mobility (TM) tester, which we developed previously. The IM checker consisted of a measuring probe, an amplifier unit, and a note-type PC. The measuring probe was designed like a dental drill to handle more easily in the mouth. The length and diameter of measuring probe were 38.5 mm and 10 mm, respectively. Since the IM checker adopted the digital data processing in order to reduce noises, the measurement reproducibility increased, compared to that of the TM tester. The IM checker was able to estimate a small implant movement objectively and quantitatively, because it was possible to discriminate the difference of movement between two artificial implant models, whose mobilities were examined as M0 by dentists. Moreover, it had a sufficient measuring reproducibility and reliability, and sufficiently short measurement time. We concluded that this IM checker could be available for implant movement examination in dental clinics.

Acknowledgments

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Table1 Result of IM score from different operators.

IM Model	Regular-type					Hard-type				
Operator	A	B	C	D	E	A	B	C	D	E
IM score	58.5	53.8	51.6	50.4	58.7	29.1	30.4	33.1	34.1	28.6
S D	0.96	2.06	1.65	3.18	3.25	1.28	2.96	1.32	0.62	2.64
Variation(%)	1.6	3.8	3.2	6.3	5.5	4.4	9.7	3.9	1.8	9.2

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岡山大学医学部保健学科紀要，11：25～34，2000

（原　著）

歯科インプラント動揺測定装置の開発

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抄　　録

臨床歯科において，歯の動揺度診査が日常的に行われているのと同じように，近年行われるようになってきた歯科インプラント施術においても，その植立評価は重要である。歯の動揺は，歯の治療計画において，また予後の評価においても重要な情報を与えてくれる。本研究では，その植立評価を行うために，インプラントの動揺に着目した。動揺を簡便にかつ定量的に測定するために，著者らがすでに開発したＴ－Ｍテスタ（Tooth Mobility tester）を改良して，IMチェッカ（Implant Mobility Checker）を開発した。IMチェッカは測定プローブと増幅器などのインタフェース，演算処理用のノートパソコンから構成される。測定プローブは圧電素子を２枚重ねたバイモルフ構造で，単一周波数の振動駆動と加速度検出を行い，口腔内でも測定ができるほどに小型に設計した。ノートパソコンでは得られた加速度信号をデータ処理し，IM値を算出する。IM値は，測定周波数と駆動力が一定の場合，インプラント周囲の機械モビリティに比例するので，インプラントの動揺を数値化することができる。内可動性機構をもつIMZタイプのインプラントを埋植したモデルを製作し，そのIM値を測定した。インプラント周囲の材料（モルテノ®）の硬さを変えた２種類のモデルを作製したところ，歯科医による臨床的動揺度診査はいずれもM0であったが，本チェッカによってその動揺の差を測定したところ，IM値は29と58となり，客観的に動揺の差を評価することができた。試作したIMチェッカで測定したところ，一歯の測定時間は約15秒以下であり，また測定のばらつきは術者内で平均６％以下，また術者間で６％以下であった。一方，従来のアナログ型Ｔ－Ｍテスタと比較したところ，天然歯の測定において，測定のばらつきは51％，測定時間は61％減少させることができた。従って，IMチェッカは十分な測定精度を確保できており，今後，臨床での試用を行いたいと考える。

キーワード：歯の動揺，機械モビリティ，インプラント，触診

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